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SAND AND GRAVEL EXCAVATION;

PART I: THE POWER SHOVEL, THE DRAG-LINE EXCAVATOR, AND THE EXCAVATOR CRANE

BY

J. R. THOENEN

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SAND AND GRAVEL EXCAVATION[1]; PART I: THE POWER SHOVEL, THE DRAGLINE EXCAVATOR, AND THE EXCAVATOR CRANE

By J. R. Thoenen[2]

INTRODUCTION

This circular is the third of a series summarizing the technical problems involved in the production and preparation of sand and gravel. The first, Information Circular 6668, published in December 1932, discussed the problems involved in prospecting and exploration. The second, Information Circular 6689 (March 1933), dealt with the development of gravel deposits. This is part I of a paper designed to present a study of problems arising in the excavation of sand and gravel and their delivery to the treatment plant. Other circulars are planned which will discuss preparation of the material for market, plant storage, and miscellaneous subjects.

Definitions

For the purpose of this circular, excavation is defined as the recovery of sand and gravel from developed natural deposits and their delivery to a plant for market preparation.

FACTORS AFFECTING EXCAVATION

The factors which must be considered in selecting a method of excavating a gravel deposit are both economic and technologic. Economic features have been discussed by the writer in a previous paper[3] and will merely be summarized here.

It is an undisputable fact that no natural resource has a present commercial value as such unless it can be sold or used. This fact applies to sand and gravel deposits as well as to other natural resources. Therefore, unless a reachable market exists, a deposit of sand and gravel has a present commercial value equal to and governed entirely by the value of its location as land surface. This fundamental economic feature is overlooked far too often or deliberately ignored in the establishment of sand and gravel plants. Virgin deposits may have a potential value for future exploitation, but such a problematical value can have no effect upon the selection of an excavation method for immediate use.

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[1] The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is used: "Reprinted from U. S. Bureau of Mines Information Circular 6798."

[2] Senior mining engineer, U. S. Bureau of Mines.

[3] Thoenen, J. R., Economics of New Sand and Gravel Developments: Econ. Paper 7, Bureau of Mines, 1929, 60 pp.

Strictly speaking, the presence or absence of a market is not a factor in the selection of the method of excavation to be used, yet it should be the controlling factor in determining whether there shall or shall not be excavation by any method. For example, the possibility of using a cheaper method may create a market already supplied by established plants operating under the handicap of antiquated or expensive methods.

Prior to the expenditure of funds for developing a new deposit by any method, the prospective operator should for his own best interest instigate and complete a careful and conclusive market survey.

Having done this and established beyond any doubt the existence of a market for his material, then that market becomes a direct factor in the selection of his excavating method as his market survey will show what quantity of material can reasonably be absorbed and what prospects there may be for future expansion. Knowing what tonnage can be sold, he can design his plant for either a large continuous production of varied products or a small, temporary or continuous, production of one or two special products.

His market survey will also show him what quality and gradation of material he must produce. While this primarily affects the design of his treatment plant it may indirectly or in some instances even directly affect his excavation method.

Therefore a market survey of consumers' requirements is the first essential step in determining the method of excavation. This and other economic factors are discussed in more detail in the reference cited.

There are a number of technologic factors which have a direct bearing on the selection of a method of excavation. These also have been discussed by the writer in a previous publication[4] and will only be summarized here.

TYPES OF DEPOSITS

Natural sand and gravel deposits have been classified for convenience under three types; bank, pit, and marine. Pit deposits have been subdivided further as dry and wet and marine deposits as river, lake, and ocean.

The type of deposit has a direct bearing upon the selection of a method of excavation because of its physical characteristics. Thus bank deposits, except where hydraulic methods are employed, are worked dry. Pit deposits may be either dry or wet, depending upon local conditions, personal preferences, or machinery available, and marine deposits are invariably operated wet.

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[4] Thoenen, J. R., Development of Sand and Gravel Deposits: Inf. Circ. 6689, Bureau of Mines, 1933, 50 pp.

TYPES OF EXCAVATING EQUIPMENT

Irrespective of the type of deposit various types of excavating equipment may be used. The method of excavation is governed first by the type of deposit, and is influenced further by the type of machinery to be used. For example, bank deposits are dry excavations but may be operated by power shovels, dragline excavators, power scrapers, or slackline cableway excavators or by hydraulicking.

Dry pits may employ the same types of equipment as banks, but wet pits will not use the power shovel except for stripping and in some instances for removing an upper bench above water level. This in reality becomes dry-pit excavation, however. The dragline, scraper, and slackline excavator may be used in wet pits as well as the pump, clamshell, or ladder dredge. So far as the writer is aware dipper dredges have not been used in wet pits. A modification of the pump dredge is being used in the Ward jet pump which will be discussed later.

Marine deposits may employ power scrapers, slackline excavators, or any type of dredge. Draglines are less frequently used for this work, and obviously the power shovel is not applicable. If new equipment is contemplated the personal preferences of the operator, tempered by local conditions, will be the governing influence in selecting machinery and method of mining.

TYPES OF HAULAGE EQUIPMENT

The type of haulage equipment may affect the method of excavation to some extent. The function of haulage equipment is to serve excavation equipment. This point is often overlooked in planning new operations. Haulage equipment cannot transport material that has not been dug. Excavating equipment cannot function properly unless the haulage equipment can give it efficient service.

There are several types of haulage equipment that may be used with the various types of excavators. Local conditions at one deposit may eliminate all but one type, while at another deposit similar conditions may indicate the advantage of another type of haulage unit.

In banks and dry pits, mobile haulage units such as locomotives and cars, autotrucks, and portable belt conveyors are used to serve power shovels and drag-line excavators. Where the excavation has been extended beyond economic reach of the power scraper, these haulage units may be used to serve the scraper. Ordinarily, however, the power scraper does its own hauling.

At wet pits, trucks and industrial railways are used to serve the dragline and at times the power scraper. Conveyor belts are used less frequently. Where the excavating unit is the pump dredge it may do its own hauling by pumping through floating pipe lines directly to the washing plant. If the distance is too great, booster pumps may be installed in the line to act as the haulage unit. At still greater distances, the pipe line is abandoned, and barges hauled by tug boats are installed. Cableway scrapers installed in wet pits usually deliver material direct to the plant, although at a number of pits they deliver to a hopper for truck or car loading and transfer to the plant.

In marine deposits as in wet pits the power scraper or slackline excavator may deliver direct to the plant or to haulage equipment. The pump dredge may likewise deliver to barges or by booster pumps direct to the plant. Other types of dredges usually load barges of some sort. Some lake and ocean dredges are themselves the haulage equipment in that they load their own holds and when full proceed under their own power to the land plant or storage. Various combinations of haulage equipment may also be used; for example, one western plant pumps to a central bunker and uses an aerial tram to convey the material from there to shore.

AVAILABLE CAPITAL

Thus it will be seen that various methods of operation can be employed in different deposits of the same type. The prospective operator, having started his investigation by a study of economics as exemplified by market conditions and progressed through the technologic problems presented by the types of deposit, excavating equipment, and haulage equipment, must again turn to economics for a final decision as to his method of excavation. Some methods of operation involve equipment units nominal in first cost, while others require large capital investment. Some would be expensive to operate at one deposit but economical at another, while others will produce material surprisingly cheap under diverse conditions. Capital necessary for investment in the required equipment and for operating expenses must be balanced carefully against the funds available. This involves comparison of the characteristics of different types of excavators and of various combinations of excavators and haulage units in order that the final selection will be well-balanced and each component properly proportioned to serve its corresponding unit efficiently, constantly, and without excessive use of power or labor. The final capital requirements must be within the means of the operator.

LIMITATIONS, REQUIREMENTS, AND CAPACITIES OF EXCAVATING AND HAULAGE EQUIPMENT

The suitability of excavation equipment to fulfill the needs of the method of excavation, as indicated by the type of deposit, depends upon the capacity of the unit, the limitations inherent in its construction or operation, and its requirements in the way of service equipment.

Unless the study of market conditions specifically indicates the need for expansion in the future, no plant should be equipped for more than the indicated capacity. This does not mean that the units should each be held rigidly to the required capacity. Frequently an excavating unit capable of a certain maximum production will operate more economically at a somewhat lower rate. For this reason it is often advisable to install machinery of greater rated capacity than is actually required. Such installations, however, should be predicated upon greater efficiency in operation at the desired rate rather than reserve for increased future production. This applies equally to the small or large plant. Future expansion should be taken care of by additional units or replacement by larger units. No equipment can function economically when pushed beyond its designed limit.

Where production can be carried on only during certain seasons of the year but consumption is continuous, the plant capacity must be considerably in excess of average market requirements. During the short working season production must greatly exceed consumption and the surplus stock-piled. On the other hand where consumption is intermittent but production can be carried on continuously, a liberal use of stock piling enables a smaller plant to work continuously to supply its market. This permits the installation of equipment with a capacity limit considerably below peak consumption requirements.

Tempered by the preceding factors, the capacity of the excavating equipment should be somewhat greater than the determined plant capacity. The extent of this surplus will depend upon local conditions and the experience of the operator. Some consider 10 percent sufficient, while others prefer 25 percent as a minimum.

Certain types of equipment are confined to certain structural limits of operation. In other types, the limiting range is greatly extended.

The power shovel has great mobility but is limited to dry operation. It is confined to excavation of material lying above or only slightly below the working floor. Its range of operation is limited by the length of its boom and dipper stick.

The dragline is slower than the shovel in rotating and traveling speed. It can dig material above its working level but ordinarily excavates material below that level. It digs either from dry pits or below water level and has a greater range than the shovel because of its longer boom and because the bucket can be swung and cast to dig beyond the end of the boom.

The traveling crane with a boom length similar to that of the dragline also has a wider range and can operate in either wet or dry deposits. It digs with equal facility within the range of its reach from above or below its working level.

The power scraper and slackline cableway excavator have a much greater horizontal and vertical range than the three machines mentioned. They may also be used in either wet or dry deposits and dig from above or below their working level.

The clamshell dredge is essentially a crane mounted on a floating scow, although a dragline using a clamshell bucket may be so mounted. The dipper dredge is essentially a power shovel on a similar mounting, although the mechanical arrangement is necessarily different. The pump dredge and ladder dredge are essentially marine equipment and are limited to excavation below water level. The four types of dredges differ materially in their structural and operating limitations. They are discussed in part III of this series.

The power shovel is not capable of transporting material any great distance. Shovels with long booms and dipper sticks sometimes can transfer overburden from its natural position to the excavated pit, and in this sense the shovel may be a transportation unit. Its range of transfer ability, however, is limited to the reach of its structural characteristics.

The dragline excavator, like the power shovel, is not a transporting unit. However, owing to its greater reach it is used more frequently for casting material, such as overburden, to one side. The same is true of the traveling crane with a clamshell or orange-peel bucket.

All three types therefore must ordinarily be served by some type of transportation unit. The type best suited to the needs of any particular deposit will depend upon local conditions, and where there is an equal choice between two or more types the experience of the operator will govern.

The power scraper or slackline excavator, on the other hand, is both an excavator and a transportation unit within its operating range. Usually it is set up to dig material in the pit and deliver it to the receiving hopper at the plant in one operation. Since most gravel pits are not replenished seasonally, the power scraper, like other units, ultimately reaches its limit of range and must then depend upon other means of transportation. All types of haulage equipment available for the shovel or dragline are also available for the scraper. Unlike the shovel, dragline, and crane, a second scraper may be set up to relay material from the digging scraper to the plant. This second unit thus becomes the transfer agent serving the first. In fact, the scraper itself may be utilized as the transportation equipment not only for the shovel and dragline but also for dredges. In a few instances where river deposits are replenished periodically by floods, the scraper works over the same area year after year and needs no additional haulage equipment.

The pump dredge, as previously mentioned, may also be installed as both an excavator and transportation unit by pumping dredged material direct to the plant. As distance increases, however, the transfer operation becomes too great for the dredge pump, and it is supplemented by a booster pump or barges.

Clamshell, dipper, and bucket dredges are not transportation units in themselves and must be served by barges.

It is thus seen that there is not only a wide choice of equipment available for the sand and gravel producer, but each unit has a rather wide variation in its capacity, operating limits, and requirements.

HAND EXCAVATION

Considerable sand and gravel were produced in the early days, and still are in small pits, by the use of hand labor loading horse-drawn wagons or dump carts. The next development was the use of drag scrapers drawn by horses or mules. These were followed by tractor-drawn scrapers, which are used efficiently in some plants at the present time.

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The "drag" or "slip-scoop" scraper ranges in rated size from 3 cubic feet for operation with one horse or mule to 5 and 7 cubic feet for teamwork. Because of spillage the actual capacity of drag scoops is seldom over 50 percent of their measured capacity. They are economical for haulage distances not greater than 200 feet. Sand and gravel can be loaded by their use for 7 to 15 cents per cubic yard depending on the length of haul.

Fresno scrapers are similar to drag scoops except that they are larger and have runners attached to facilitate dumping and empty travel. They range in rated capacity from 8 to 18 cubic feet with about 50 percent actual operating capacity. The economic hauling distance ranges from 200 to 300 feet, and four horses or a gasoline tractor commonly are used for motive power. Costs range from 10 to 20 cents per cubic yard.

Wheeled scrapers are similar to Fresno scrapers except that the runners are replaced by wheels and the scraper is equipped with a pole. They also have a lever by which, when loaded, the scraper is raised and carried on the wheels to the dump. They are built in sizes ranging from 9 to 27 cubic feet capacity, and because carried clear of the ground their actual operating capacity is 60 to 75 percent of their rated capacity. The wheel scraper usually is drawn by a single team or tractor. With team haulage it is customary to use an extra snatch team or tractor while loading.

They may be used on hauls of 300 to 400 or more feet economically. Operating costs range from 10 to 20 cents per cubic yard, depending upon the haulage distance and size of the scraper.

In cemented gravel or hardpan extra teams or tractors are required to loosen the gravel by plowing ahead of the scraper. This may increase production costs by as much as 50 percent in some cases.

For sand and gravel production scrapers are used to dig and haul the gravel to the transportation equipment, which in turn transfers it to the washing plant. Transportation equipment may be either standard gage railway or industrial cars or conveyor belts. The usual procedure is to build a ramp over the track with a hole through which the gravel is dumped to the car below. For conveyor belt loading the ramp is built over the receiving hopper.

Scraper excavation is limited to small production in bank or dry pit deposits. It is economical for temporary installations and requires a minimum of capital investment. Scrapers also are used rather extensively in stripping thin overburden.

MECHANICAL EXCAVATION

By far the major production of sand and gravel is excavated by mechanical equipment. The following table is abstracted from the census for sand and gravel for 1939. Plants producing less than 25,000 tons annually were not included in this tabulation.

TABLE 1.--Principal statistics, by type of operation, for the United States, 1929

Type of operation	Number of enterprises	Number of plants	Quantity, short tons
Total	957	1,163	168,885,667
Bank only	109	123	17,461,341
Bank and pit	177	234	38,051,909
Pit:			
Wet	303	258	30,920,020
Dry	129	144	20,619,691
Dry and wet	34	41	5,462,507
Pit and marine	63	90	12,185,899
Marine:			
River	194	220	30,140,191
Lake	17	18	4,329,171
Ocean	5	5	3,361,345
River and lake	7	8	2,365,708
Other	14	24	3,987,885

This table indicates that over 76,000,000 tons, or probably 50 percent of the country's production, as represented by the Census figures for 1929, was produced from dry excavations.

Another table in the same publication shows that power shovels account for over 43,000,000 tons and draglines for over 25,000,000 tons. The designation "dragline" in that publication includes power scrapers and slack-line cableway excavators as well as dragline excavators. From this it must be assumed that the power shovel accounted for about 30 percent of the total production or 60 percent of the production from dry excavations.

The pump dredge in the Census report is credited with over 42,000,000 tons, thereby holding a position in wet excavation similar to that of the power shovel in dry work.

It is, therefore, apparent that these two types of equipment are the most popular in their fields. The dragline (including scrapers) takes second place in dry excavation. In wet escavation the Census tables do not show the relative popularity of draglines and ladder dredges, but presumably the tonnage produced by them is about equal.

It is of further interest to note that the same Census report shows that of the power used by mobile equipment (pit excavating machinery) in sand and gravel plants 61 percent was supplied by steam engines, 22.5 percent by internal-combustion engines, and 16.5 percent by electric motors. Of interest in this record is the fact that since 1928 few gravel excavators have been built for steam power except on special order. As a result the ratio for steam power is undoubtedly much lower at present.

A further interesting comparison from the same Census report is given in the following table:

TABLE 2.--Installed horsepower in gravel excavators

Type of excavator	Installed horsepower	Production, tons	Tonnage produced per rated horsepower
Power shovel	135,854	43,164,891	318
Drag line1/	73,170	25,180,280	345
Pump dredge	144,186	42,505,275	295
Ladder dredge	48,680	16,470,548	338

1/ Includes power scrapers and slack-line cableway excavators.

THE POWER SHOVEL

The power shovel, drag-line, and traveling crane are commonly built on the same chassis. Fundamentally they are much alike. The difference lies in the superstructure mounted on the chassis, which greatly distinguishes the type and range of operation of the three machines.

Structural limitations.--The power shovel is limited first of all to dry excavation. It cannot excavate material below water except from very shallow depths.

The design of the shovel limits its field to excavation of material above the floor on which the shovel operates, except as it is modified to allow digging to a comparatively shallow depth below this level, enabling such a unit to advance into a cut on a descending grade.

The lateral or vertical reach of the shovel is governed by the length and angle of boom and the length of the dipper stick. Each size of shovel can be equipped with different lengths of boom and dipper stick so that each size has considerable range. In some shovels the boom angle can be varied at will, while in others the angle is permanent. Since no shovel can operate if the necessary lift exerted at the extended dipper is sufficient to overturn the shovel, each extension of the length of boom or stick and lowering of the boom angle must be compensated by a reduction in dipper load or size of dipper. Thus, while one type of shovel with a certain length of boom and dipper stick may wield a 2-cubic-yard dipper, it may not be safe to use more than a 1 1/4- or 1 1/2-cubic-yard dipper with longer boom and stick. Since the rotating speed is reduced with longer booms, the extension of reach is at the expense of capacity.

Shovels using electricity as primary motive power can operate only when within the reach of power cables. Those in which the primary power is steam, gasoline, or oil, on the other hand, can operate independently under their own power. The power shovel excavating sand and gravel usually is put to work against a bank where it will have little need for movement over long distances. Travel speed thus becomes of minor importance. This lessens the objection to trailing cables in supplying electric power.

The mobility of the power shovel is governed by the design of its means of locomotion. Early shovels were built to move only on standard- or wide-gage railway tracks. These were known as "railway-type" shovels. Many shovels of this type were and still are used in quarries and gravel pits. Their operation is curtailed by the necessity for providing sectional track for each advance into the bank. This requires the time and expense of a pit crew in preparing the roadbed and moving and connecting the track sections. When standard-gage track was used the stability of the shovel was low because of the narrow base, and it was necessary to resort to the use of heavy arms extended from the shovel frame so that they could be jacked to the ground on either side and thus increase the stability by widening the support. These jacks had to be loosened and reset for each move, thus requiring more time between digging periods.

To avoid these difficulties, railway trucks were replaced on some shovels by wide-tired steel wheels. The designation "traction shovel" was given to this type of locomotion. It enabled the shovel to move without track, but because of the concentration of weight on even, wide tires trouble was encountered in moving over soft ground. To obviate this difficulty, heavy timber mats were employed to provide a solid roadway over which the shovel could be moved. These mats were built in sections and could be moved by the shovel by chaining them to the dipper. This somewhat reduced the size but did not entirely eliminate the pit crew. Spreading the gage of the traction wheels increased the stability of the shovel, and the jacks were not necessary. On hard bottom, such as in rock quarries, mats were not necessary.

The modern caterpillar crawler mounting was developed further to solve the problem of mobility. With caterpillar crawlers the weight of the shovel is distributed over a much greater area and is thus reduced per unit of area. No pit crew is needed to move track or mats, and the machine moves over hard or soft ground with ease. By independent control of each crawler the turning radius of the shovel is also greatly reduced.

As originally built, the railway-type shovel could revolve only through a limited arc. The introduction of traction and crawler mountings brought with them the full-revolving shovel capable of rotating 360° and digging from any point in the circle.

The power shovel operates on a comparatively level floor. In the light and intermediate sizes it can negotiate grades up to 30 percent if the condition of the ground surface is such that the available tractive force may be applied, but for continuous operation it works best on the level. Designed to remove material from above its floor level, it must excavate the bank as it comes to it. Selective mining is difficult. This means that the shovel cannot leave in place those parts of the deposit which are not marketable. The shovel can remove them and load waste cars for disposal over the waste

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dump, but they must be removed as the shovel proceeds. If these waste areas are large the shovel can work around them and leave them in place. Many deposits, however, contain small lenses of clay or fine sand which the operator would like to avoid. In this sense the power shovel is not suited for selective mining.

Service equipment required.--The power shovel is not in itself a haulage unit. Its range of transportation is limited to the reach of its boom and dipper stick. Therefore it depends upon some form of service equipment in delivering the material it digs to the treatment plant. Almost any of the ordinary types of service equipment may be used to supplement shovel operation. The type selected will depend upon local conditions and the personal preference of the operator. The efficiency with which the material is removed from the shovel will greatly affect the shovel operation and consequently the output. It is no uncommon sight to find a shovel idle because the transportation unit has failed temporarily in its function. Power shovels afford a continuous service, and to work with greatest efficiency they should be served by transportation equipment affording a like service. If the service unit is intermittent in its function the shovel must be idle unless the period of intermittency is less than the operating cycle of the shovel.

As previously stated, the electric shovel must be served by a power cable. Power is usually brought by permanent pole line to within a short distance of the shovel. Connection between power line and shovel is ordinarily made by flexible armored cable dragged behind the shovel or carried on a reel on the shovel superstructure or in a separate mounting near the shovel. Each advance of the shovel necessitates adjustment in cable length. With either a dragging cable or reel the adjustment is usually automatic for short shovel advances, as usually at least 1,000 feet of cable is used. Shifting the cable to another connection with the power line ordinarily does not require an appreciable loss of time when properly supervised.

Steam and gas- or oil-powered shovels require attendant vehicles in supplying fuel. Coal, oil, or gasoline usually are supplied to the shovel by the haulage unit, although sometimes this is not practicable as in the case of a conveyor belt used as a haulage unit. Temporary pipe lines ordinarily are laid for water supply to steam machines. Similar lines sometimes are used to bring gasoline or fuel oil to the shovel.

The information shown in tables 3 and 4 has been taken from catalogs of various shovel manufacturers to present in condensed form the different sizes of shovels available and their minima and maxima limits of range, specifications, and power.

Columns showing minimum and maximum average working capacities have been added from table 9 for convenient reference.

Figure 1 illustrates the shovel working ranges referred to in table 3.

There may be some confusion in the study of these tables as certain machines are equipped with different sizes of dippers for use on different lengths of dipper sticks and booms. Thus a machine designed for normal operation with a 1-yard dipper on a short boom and dipper stick may be furnished with a 3/4-yard dipper on a longer boom and dipper stick for different working conditions. The tables are not presented with the idea of recommended sizes for sand and gravel excavation. Their function is merely to present to the reader the sizes, ranges, and power plants which are available in the open market. Detailed selection of size and range must be left to local conditions and the mechanical details of the particular machines involved.

Capacity.--The rated or theoretical capacity of a power shovel depends upon a number of factors, among which are the size of the dipper; the type and application of the source of power; the hoisting, crowding, swinging, and traveling speeds; the speed of swing acceleration and deceleration; the type of mounting; and the ease of operation.

The actual or working capacity of any unit is affected by all of these items and, in addition, by others, such as weather conditions, the height of the bank, the character of the material to be dug, the service rendered by the haulage equipment, and the efficiency of the operator. There is no exaggeration in the statement that the same shovel on different classes of work, operating under different conditions and personnel, may vary as much as 500 percent in its working capacity.

The mechanical factors from which the theoretical capacity is calculated may be controlled by selection from a wide range offered by manufacturers. Dipper sizes range from 3/8 to 20 cubic yards in capacity. Boom and dipper stick lengths also are available over a wide range.

Originally powered by steam, shovels have gradually been adapted to other types of power; recent types include the gasoline and fuel-oil internal-combustion engines, the semi-Diesel or full Diesel engine, and the direct- and alternating-current motor. In addition, combinations of Diesel or gas engines with compressed air or electric motors have been supplied.

The speed of shovel motion, both in digging, rotation, and travel, has been increased.

Crawler or caterpillar traction has almost completely replaced the original railway truck and the later wide traction wheel.

Early shovels were limited in their rotation cycle, but most of the recent shovels, both in small and large sizes, are capable of a 360° swing.

With mechanical improvements the labor required to operate a modern shovel has greatly decreased. The early steam-operated, railway-type shovel required a shovel runner, a craneman, a fireman, and a ground or pit crew to shift track as the shovel advanced. The modern shovel is operated by one or two men with much less effort.

TABLE 3.--Power-shovel working ranges

Dipper capacity, cubic yards	Working capacity, tons per hour		Angle of boom, degrees		Length of boom, feet		Length of dipper stick, feet		Maximum dumping radius, feet		Maximum digging radius, feet		Maximum dumping height, feet		Maximum digging height, feet		Maximum width of level cut at grade, feet		Maximum cut below grade, feet	
	From	To	From	To	From	To	From	To	From	To	From	To	From	To	From	To	From	To	From	To
3/8	38	67	30	60	12	17	8.3	13.3	11.8	20.6	13.7	23.8	6.3	17.5	12.0	22.5	14.0	29.2	0.3	6.7
1/2	50	92	40	60	16	21	11.0	15.0	15.0	26.3	18.8	29.6	10.7	20.0	16.5	25.8	19.0	41.0	1.5	8.3
3/4	74	131	35	65	16.8	23.0	12.5	19.0	16.7	29.3	23.2	32.8	11.0	25.7	16.8	32.7	24.5	38.2	2.3	11.9
1	95	177	35	55	18.0	26.0	12.5	19.5	16.5	31.5	24.0	35.5	11.2	27.2	17.8	35.2	28.2	48.7	2.3	11.7
1 1/4	117	206	35	65	18.0	36.5	14.0	22.5	16.8	38.0	25.4	41.0	11.9	30.0	18.9	38.8	29.2	48.3	1.5	12.8
1 1/2	140	265	35	65	19.0	39.0	14.0	23.6	18.4	38.3	25.8	41.0	12.7	28.8	20.0	37.5	29.5	51.7	3.0	10.4
1 3/4	163	305	45	60	22.3	36.5	16.0	22.5	23.3	37.0	29.7	40.8	15.3	27.8	22.8	36.5	36.5	51.0	4.2	9.3
2	187	318	40	55	25.0	48.0	16.0	32.0	26.3	54.0	30.0	57.5	15.0	35.5	22.8	44.0	37.5	66.0	5.0	9.0
2 1/2	226	357	40	55	29.0	60.0	20.0	38.0	32.5	74.0	38.0	80.0	19.5	39.0	29.0	40.0	46.0	80.0	5.2	10.3
3	271	429	45	55	32.0	45.0	20.6	30.0	34.8	54.3	42.0	48.5	21.5	35.8	31.0	40.8	47.5	68.0	5.0	9.0
3 1/2	263	444	45	55	34.0	75.0	22.0	48.0	37.0	85.0	40.5	90.0	22.8	54.0	32.8	70.0	53.0	100.0	6.0	9.3
4	301	530	45	50	32.0	75.0	22.0	56.0	38.8	88.0	42.8	91.5	21.5	59.3	31.8	70.8	51.5	103.0	7.5	17.8
5	337	633	45	-	-	75.0	-	50.0	-	82.3	-	86.5	-	58.5	-	71.5	-	103.0	-	12.5
6	412	761	45	-	72.0	90.0	46.0	58.0	76.3	101.0	80.8	109.0	56.0	58.6	69.8	71.0	98.0	130.0	4.0	11.0
8	407	750	45	47.5	85.0	95.0	58.0	62.3	99.0	103.0	105.0	110.0	57.0	71.8	-	86.5	125.0	132.0	-	-
10	509	940	47.5	-	-	87.5	-	55.8	-	95.0	-	100.3	-	62.5	-	77.0	-	117.5	-	-
12	563	1,130	45	47.5	87.5	97.5	53.8	67.5	93.3	108.0	98.8	113.5	61.0	75.0	76.3	92.5	110.0	131.0	-	14.0
14	656	1,315	-	50	-	97.5	-	61.5	-	101.0	-	107.0	-	68.0	-	85.0	-	126.0	-	-
16	750	1,508	44	50	85.0	95.0	56.0	59.5	95.8	97.5	101.8	104.0	64.8	66.0	81.5	85.8	118.5	123.0	-	11.0
20	905	1,985	-	50	39.0	95.0	60.0	60.25	-	95.0	-	107.9	-	66.5	-	85.5	-	124.0	-	11.8

TABLE 4.—Power-shovel weights and power plants

Dipper capacity, cubic yards	Working weight, pounds		Gasoline							
			Minimum				Maximum			
	From	To	Horse-power	Cylin-ders	Stroke and bore	R.p.m.	Horse-power	Cylin-ders	Stroke and bore	R.p.m.
3/8	18,000	28,200	37	4	4 by 5	1,200	45	6	3 3/8 by 4 3/4	1,000
1/2	25,000	46,000	43	4	4 1/2 by 6	1,000	55	4	5 by 6 1/4	1,000
3/4	32,000	60,000	45	4	4 1/2 by 6 1/4	1,000	110	6	5 1/4 by 6 1/2	1,140
1	60,000	94,500	80	4	6 by 7	875	135	6	5 1/2 by 6 1/2	1,140
1 1/4	71,000	141,000	92	4	6 1/4 by 8	820	135	6	5 1/2 by 6 1/2	1,140
1 1/2	73,000	165,800	92	4	6 1/2 by 7	865	160	6	6 by 7 1/4	1,100
1 3/4	109,000	166,000	120	4	6 3/4 by 7	1,000	160	6	6 by 7 1/4	1,100
2	134,500	209,500	150	6	6 by 7	975	160	6	6 1/2 by 7	1,000
2 1/2	188,000	270,000	-	-	-	-	-	-	-	-
3	211,000	340,000	-	-	-	-	-	-	-	-
3 1/2	315,000	353,400	-	-	-	-	-	-	-	-
4	351,500	450,000	-	-	-	-	-	-	-	-
5	400,000	550,000	-	-	-	-	-	-	-	-
6	550,000	1,350,000	-	-	-	-	-	-	-	-
8	-	1,450,000	-	-	-	-	-	-	-	-
10	-	1,450,000	-	-	-	-	-	-	-	-
12	1,450,000	1,950,000	-	-	-	-	-	-	-	-
14	-	1,950,000	-	-	-	-	-	-	-	-
16	1,855,000	1,950,000	-	-	-	-	-	-	-	-
20	-	-	-	-	-	-	-	-	-	-

TABLE 4.--Power-shovel weights and power plants--Continued

Dipper capacity, cubic yards	Diesel								Electric	
	Minimum				Maximum				Minimum	Maximum
	Horse-power	Cylin-ders	Stroke and bore	R.p.m.	Horse-power	Cylin-ders	Stroke and bore	R.p.m.	Horse-power	Horse-power
3/8	-	-	-	-	-	-	-	-	15	-
1/2	-	-	-	-	50	3	6 by 8	650	30	-
3/4	-	-	-	-	80	4	6 by 8	900	60	75
1	80	4	6 1/2 by 8 1/2	550	105	4	6 1/2 by 8 3/4	800	50	75
1 1/4	80	4	6 by 7	865	115	4	6 1/2 by 8 3/4	850	50	100
1 1/2	85	4	7 by 8 1/2	500	153	6	6 1/4 by 8 3/4	1,000	50	100
1 3/4	148	6	6 1/4 by 8 3/4	900	153	6	6 1/4 by 8 3/4	1,000	50	125
2	150	6	8 by 9 1/2	450	-	-	-	-	100	150
2 1/2	-	-	-	-	-	-	-	-	150	200
3	-	-	-	-	210	6	9 by 10 1/2	500	125	250
3 1/2	-	-	-	-	270	5	10 by 12 1/2	300	250	450
4	-	-	-	-	-	-	-	-	250	-
5	-	-	-	-	-	-	-	-	-	640
6	-	-	-	-	-	-	-	-	640	800
8	-	-	-	-	-	-	-	-	600	800
10	-	-	-	-	-	-	-	-	-	800
12	-	-	-	-	-	-	-	-	600	850
14	-	-	-	-	-	-	-	-	-	800
16	-	-	-	-	-	-	-	-	800	850
20	-	-	-	-	-	-	-	-	800	900

In a consideration of the shovel as a working unit, its capacity is measured by the amount of material it can dig and load in a given interval of time. Other things being equal, the theoretical capacity for a few minutes operation would be the same as the working capacity. However, the other factors never are equal, and the calculation or estimation of working capacities must take into account the influence of those factors. The estimate of capacity in which the gravel operator is interested is that which is computed with due consideration to all possible delay factors. To make such a computation it is necessary to evaluate such delays. Numerous attempts have been made to assign the proper multiplier for each type of delay factor and by their use to compile a formula from which the working capacity of a shovel may be computed for a variety of conditions. The author, however, does not feel that these factors can be reduced to mathematical precision.

A short operating season will materially reduce the annual capacity. Local rains will prevent operation for days or parts of days.

The height of the bank will affect capacity. It is true that bank heights do not vary suddenly in a well-developed gravel pit. However, shallow banks cause more frequent shovel moves, and increased moving time decreases operating time and thus capacity. On the other hand, banks of excessive height often cause delay because of the necessity of caving the top to prevent dangerous slides. The economical height of any bank depends upon the size of the shovel, length and angle of boom, length of dipper stick, and character of the material in the bank.

Obviously a bank of cemented material or one containing a mixture of boulders and fine sand will be more dangerous when worked in high benches than one containing material that caves and runs freely after each bite of the shovel dipper.

The character of the material in the deposit also has a direct bearing on the shovel capacity. Sand and gravel containing beds of cemented material or hardpan require much more power in the crowding and hoisting motions of the shovel. These motions necessarily are slowed up in such material, thus reducing capacity. The presence of boulders about the size of the dipper or larger also cuts down capacity as they must be moved to one side out of the shovel's way. This requires time.

The type of service equipment used has a very important bearing on shovel capacity. If locomotives and cars are used the larger the car the less delay there will be for the shovel. Trains must be moved to spot cars within reach of the shovel. If they cannot be moved while the shovel is loading its dipper it must lose time in waiting. At many places the length of haul from shovel to plant is such that with one locomotive in use the shovel would be idle 50 percent or more of its time waiting for cars. Even where more than one locomotive and train are used the shovel is commonly subject to delays from this cause. The field belt conveyor with portable hopper provides almost continuous service for the shovel but cannot be used under all conditions. Frequent advances of the shovel itself mean corresponding shifting of the hopper or conveyor belt, or both. Next to the weather, transportation equipment is probably most responsible for shovel delay.

A further factor affecting the shovel capacity is the excavation method itself. Bank or pit deposits usually are developed so that the shovel can load to one side and thus dig and load through an operating swing ranging from 45° to 135°, or an average of 90°. In thoroughcut development the shovel usually must load cars spotted behind it which requires an operating swing of more than 135°. At times empty cars are spotted on top of the bank. The shovel must then elevate its load above the digging position to reach the car. Obviously the position of the car to be loaded will affect the loading time and hence the shovel capacity.

The last but by no means the least important factor is the efficiency of the operator. No shovel can dig gravel by itself. Its every motion is controlled by the man at the levers. The efficiency of this control depends upon the human equation and the mechanical construction. The shovel will respond only to the impulse started at the controls. If the operator is experienced, alert, and fast, the shovel will respond accordingly. In this respect ease of manipulation due to mechanical construction, through its influence on the operator, affects the work of the shovel. If the location of the controls is such that it is difficult for the operator to see the dipper at all times or at any point of its swing hie efficiency is cut down and likewise that of the shovel. The capacity of a given shovel operating under industrial conditions may be 100 percent greater in the hands of one operator than in that of a less skillful man.

A. E. Holcomb, in an article entitled "Output Factor for Excavation Equipment," published in the October 1930 issue of Civil Engineering, discussed the variation in shovel capacity due to diverse conditions. He gives certain tables, multipliers, and formulas for computing capacity and closes by saying, "The results obtained with the mechanical excavation and handling of materials should be reasonably in accord with the foregoing estimates (capacities) if no contingency prevents." The trouble is that almost invariably some contingency arises to prevent theoretical capacity based on formulas.

Various other authorities have constructed mathematical formulas to guide the operator in judging the capacity of shovels, but in each case some such amending statement is added.

For example, using Holcomb's calculation, a shovel equipped with a 1-cubic-yard dipper loading gravel to cars spotted on the side from a bank of the most economical height and with a rotating speed of 4 r.p.m., a hoisting speed (2-part line) of 80 feet per minute, a crowding speed of 110 feet per minute, operating without delays and with each dipper filled, would theoretically load 3 cubic yards per minute or 1,440 cubic yards per 8-hour day. The author does not wish to imply that such capacity cannot be attained for a short time and possibly for the full 8 hours. However, he has never seen it done and is quite sure it could not be maintained day after day as Holcomb himself points out.

In 1929 the author published the following table[5] showing the production rates of different types of shovels operating in stone quarries. The figures include all delays of whatever nature and represent continuous production over several months.

TABLE 5.--Power-shovel duty at 41 limestone quarries, 1927

Shovel	Type	Shovel duty, tons loaded daily per cubic yard of bucket capacity
Steam ...	Railway	290
Do ...	Traction	306
Do ...	Caterpillar	324
Electric	Railway	368
Do ...	Caterpillar	476

If the last figure of 476 tons is used for electric caterpillar shovels and doubled to conform with gravel digging rather than quarry operation, 952 tons is the daily production. This would represent 634 cubic yards or only 44 percent of the theoretical capacity. The actual capacity in gravel might be somewhat above this because there would be greater probability of fully loading the dipper at each attempt than with quarry stone. A production of 634 cubic yards would be 1.32 cubic yards per minute based on an 8-hour day instead of the 3 dippers from the calculation cited. Possibly this could be increased to and maintained at 1.5 dippers per minute or 720 cubic yards per 8 hours. On the other hand, a shovel working in cemented gravel encounters conditions similar to quarry-rock work, and the rate might be greatly reduced under those conditions.

The point the author wishes to make is that delays under actual operating conditions affect production so greatly as entirely to eclipse the accuracy of mathematical calculations.

For actual working capacities of power shovels for sand and gravel excavation, the author has found the most satisfactory estimate is one half the theoretical capacity.

There are various ways of computing the theoretical capacity for a shovel. The author found the following method is simple and easy to apply.

Theoretical capacity is a function of the size of the dipper and the time required to complete the shovel cycle through loading, swinging, dumping, and returning to the digging position. The dipper capacity is fixed by size. Dipper capacities computed from heaped measurements are unsatisfactory because of the difference in the excess over struck measurement in different kinds of gravel.

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[5] Thoenen, J. R., Study of Quarry Costs: Rept. of Investigations 2911, Bureau of Mines, 1929, 12 pp.

The swing and return time is calculated from the rotating speed of the shovel, giving due consideration to accelerating and decelerating ability, and the average angle of swing. Shovel operations consist of four motions; crowding, hoisting, swinging, and racking in. Crowding, hoisting, and swinging can be performed simultaneously as can swinging, lowering, and racking in. In sand and gravel excavation the bank height is such that in most cases when the shovel has finished loading the dipper by crowding and hoisting, or all three motions, the dipper will be nearly up to its dumping height. In any case the remaining hoisting distance can be attained in finishing the swing. Therefore crowding and hoisting speeds are not considered in computing swinging and return time. Likewise, acceleration and deceleration of swing are omitted in the calculation because they occur during loading and dumping time and are covered in that calculation.

The loading and dumping time is taken arbitrarily as the average of several thousand time studies by the author and others under various working conditions.

The United States Bureau of Public Roads has made time studies of shovel operations under field conditions for a number of years. The results shown in table 4 have been abstracted from those studies.[6]

TABLE 6.--Time of shovel[1] cycles, in seconds

Angle of swing, 30° to 270°	Load	Swing	Dump	Return
Minimum average, 11,134 observations	9.4	4.5	2.1	4.2
Maximum average, 11,134 observations	12.8	8.3	4.4	7.6
Angle of swing, 90° or less				
Minimum average, 6,910 observations	8.9	3.9	2.1	3.8
Maximum average, 6,910 observations	13.6	4.6	3.5	5.9

[1] 3/8- to 1 1/2-cubic-yard shovels.

Assuming the minimum and maximum of these results as typical of the range of shovel time cycles, table 7 has been prepared.

TABLE 7.--Range of shovel cycles, in seconds

	Load	Swing	Dump	Return	Total cycle
Minimum	8.9	3.9	2.1	3.8	18.7
Maximum	13.6	8.3	4.4	7.6	33.9

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[6] Allen, T. W., and Anderson, A. P., Power-Shovel Operation in Highway Grading: Bureau of Public Roads, Dept. of Agriculture, Public Roads, vol. 8, no. 12, February 1928, p. 251.

Theoretical swing and return times for individual shovels have been calculated by the author on the basis of rotating speed as given in manufacturers' catalogs in the following manner.

Side loading with an average swing of 90° a shovel will average 180° to complete the cycle. If its rotating speed is 4 r.p.m. the time of average swing and return motions may be calculated as follows:

$$\frac{\text{60 seconds times 180°}}{\text{360° times 4 r.p.m.}} = \text{7.5 seconds.}$$

Manufacturers' catalogs show 3/8- to 1 1/2-cubic-yard shovels having rotating speeds of 3 to 6 r.p.m. By calculation the combined swing and return times for an average 90° swing would be 5 to 10 seconds. This range compares with the minimum of 7.7 seconds and the maximum of 15.9 seconds in table 7. The times swing cycles are thus found to be about 65 percent slower than the theoretical ones. This is undoubtedly due to the time required for acceleration and deceleration.

Table 8 has been computed to show the theoretical cycle of various shovels based on their given rotating speed and assuming the minimum and maximum loading and dumping time of table 7, 11.0 and 18.0 seconds.

Given the theoretical minimum and maximum cycle time for various rotating speeds as computed in table 8, the theoretical shovel capacity may be estimated in cubic yards per hour as follows:

$$\frac{\text{3,600 seconds times dipper capacity in cubic yards.}}{\text{Cycle time in seconds (from table 8)}}$$

Thus a shovel with a 2-cubic-yard dipper and a rotating speed of 3 r.p.m. would have a theoretical capacity ranging from 257 to 345 cubic yards per hour.

Power shovels equipped with dippers of the same size but made by different manufacturers are shown by catalogs to have different rotating speeds. A study of the catalogs of a number of manufacturers gives the minimum and maximum rotating speeds for each dipper size, as shown in table 9.

From these rotating speeds and the time cycles of table 8, the theoretical and working capacity ranges of various shovels has been estimated in table 9.

TABLE 8.--Theoretical time required for power-shovel cycles (seconds);
Average swing, 90° 1/

Speed of shovel rotation, r.p.m.	Swing and return	Complete cycle	
		Minimum	Maximum
0.5	60.0	71.0	78.0
.8	37.5	48.5	55.5
.9	33.3	44.3	51.3
1.0	30.0	41.0	48.0
1.1	27.3	38.3	45.3
1.5	20.0	31.0	38.0
1.65	18.2	29.2	36.2
1.8	16.7	27.7	34.7
2.0	15.0	26.0	33.0
2.5	12.0	23.0	30.0
2.75	10.9	21.9	28.9
3.0	10.0	21.0	28.0
3.1	9.7	20.7	27.7
3.2	9.4	20.4	27.4
3.25	9.2	20.2	27.2
3.5	8.6	19.6	26.6
3.6	8.3	19.3	26.3
3.75	8.0	19.0	26.0
4.0	7.5	18.5	25.5
4.1	7.3	18.3	25.3
4.25	7.1	18.1	25.1
4.3	7.0	18.0	25.0
4.5	6.7	17.7	24.7
4.75	6.3	17.3	24.3
5.0	6.0	17.0	24.0
5.25	5.7	16.7	23.7
5.5	5.5	16.5	23.5
6.0	5.0	16.0	23.0

1/ Load and dump time, 11.0 to 18.0 seconds (assumed from table 7).

TABLE 9.—Estimated theoretical range of shovel capacity

Dipper size, cubic yards	Rotating speed, r.p.m.		Theoretical capacity, cubic yards per hour		Capacity in tons per hour			
					Theoretical 1/		Working 2/	
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
3/8	4.0	5.5	53	83	77	133	38	67
1/2	3.5	6.0	68	113	99	183	50	92
3/4	3.5	5.25	102	162	148	262	74	131
1	3.1	5.5	130	218	189	353	95	177
1 1/4	3.0	4.5	161	254	233	412	117	206
1 1/2	3.0	5.5	193	327	280	530	140	265
1 3/4	3.0	5.5	225	377	326	610	163	305
2	3.0	4.1	257	393	373	636	187	318
2 1/2	2.75	3.2	311	441	451	714	226	357
3	2.75	3.2	374	530	542	858	271	429
3 1/2	1.8	2.5	363	548	526	888	263	444
4	1.8	2.75	415	654	602	1,060	301	530
5	1.5	2.5	464	783	673	1,267	337	633
6	1.5	2.5	568	9930	824	1,522	412	761
8	.9	1.5	562	930	815	1,500	407	750
10	.9	1.5	702	1,160	1,018	1,880	509	940
12	.8	1.5	776	1,394	1,125	2,260	563	1,130
14	.8	1.5	905	1,625	1,312	2,630	656	1,315
16	.8	1.5	1,034	1,860	1,500	3,015	750	1,508
20	.8	1.65	1,230	2,457	1,810	3,970	905	1,985

1/ Sand and gravel estimated to range from 2,900 to 3,240 pounds per cubic yard.

2/ Assumed as one half theoretical capacity. This drastic reduction from theoretical capacity is designed to account for delays of any nature and at the same time to avoid detailed and exact calculations involving the relation of accelerating and decelerating ability in machines of different size and design upon the time of the shovel cycle. Thus reasonable accuracy is obtained by simple calculation without a technical discussion of the effect of different mechanical details.

THE DRAGLINE EXCAVATOR

The term "dragline" as commonly used in describing excavating machinery unfortunately has been corrupted to include three types of excavators. These are the dragline excavator to which the term applies correctly, the power scraper, and the slackline cableway excavator. The error is understandable in that all three machines load their buckets by dragging them over the ground. Except for this one feature in common, however, there is no similarity of operation.

The dragline excavator resembles a power shovel in that it is commonly mounted on the same type of chassis. The superstructure of both dragline and shovel consists of a housing for the power plant and a boom. They differ in that the dragline has no dipper stick.

Like the shovel, the dragline is self-contained without accessory equipment other than the transportation unit which serves it.

The power scraper and slackline cableway excavator on the other hand are dual units consisting of a head mast and tail anchorage mounted on separate bases but connected by one or more cables. Either head mast or tail anchorage, or both, may be mounted on a movable chassis, but usually both are stationary.

The similarity of the dragline to the shovel ends with its chassis, housing, and boom. In fact, it is probably erroneous to include the boom as a similar element. Like the shovel, the dragline is available in many sizes and structural ranges, but its boom is longer, of different construction, and serves a somewhat different purpose than that on the shovel.

Operation of the dragline differs radically from that of the shovel. Whereas the shovel removes a horizontal slice from the deposit by individual bites of the dipper moving in a vertical plane, the dragline removes either horizontal or inclined slices by dragging the bucket through inclined or horizontal cuts. The shovel operates by pushing its dipper into the foot of the bank and lifting it through the gravel. The dragline drops its bucket on the top of the bank and drags it along the surface to fill it. Thus one pushes and lifts its dipper while the other drags and lifts its bucket.

The function of the shovel boom is to provide a mounting for the dipper stick which in turn provides the means by which the dipper is actuated in a vertical plane. The combination of horizontal radial motion of the boom and vertical radial motion of the dipper stick permits great flexibility and control within the structural limits of the machine. The dragline boom acts as a radial arm, the only function of which is to permit the operator to hoist the bucket and swing it horizontally.

The drag cable to a certain extent takes the place of the dipper stick. When swung and placed in position for digging, the drag cable pulls the bucket toward the machine thus cutting a path through the material and filling itself.

In sand and gravel excavation the dragline boom must be held stationary while the bucket is being loaded. Like the shovel, however, the bucket can be hoisted and the boom swung simultaneously. The bucket can also be lowered while swinging.

The difference in the loading motions of the shovel and dragline provides the basis for a radically different method of excavation. The dragline operates from a position on top of the bank to be dug and often from on top of the overburden overlying the deposit. It retreats ahead of the advancing end cut or proceeds parallel to a side cut.

From the vantage point of its position on the ground surface it can dig material from below the ground water level without having first to drain the pit.

From this position it can also remove the overburden from the gravel, then remove the gravel below without changing its position. A further advantage due to this position of the machine is its ability to revolve the boom through 180° and by shallow cuts prospect the ground ahead of the advancing cut. If barren ground is encountered it can be moved over the spot and can excavate beyond it with little inconvenience or loss of time. Thus a certain amount of selective mining can be done by the dragline.

This position of the dragline on the ground surface is considered disadvantageous by some writers because of the difficulty of moving such a heavy piece of machinery over a rough surface. The author's experience, however, shows this difficulty to be of minor importance because the dragline in nearly all cases can reverse itself and prepare its own roadway.

Draglines commonly are mounted upon caterpillar trucks, but often a skid-and-roller type of mounting is used, and one manufacturer provides locomotion by enabling the machine literally to lift and move itself bodily by successive steps. Wide traction wheels are seldom used because of the difficulty of operating them over the soft material usually found on the surface.

The skid-and-roller type is mounted upon a wide, flat metal or wooden base resting on wooden or metal rollers which move over timber mats placed on the ground. Motion is obtained by anchoring the bucket and pulling the machine towards it.

The other type is known as a walking dragline. It has a circular base resting directly on the ground surface. The area is sufficient to provide a stable foundation even in soft ground. This base remains stationary while the dragline revolves upon it. A heavy steel shaft runs through the dragline at right angles to the long axis of the boom. This shaft extends outside the housing and on each end has a structural steel "foot" built in the shape of a flat-bottomed boat. These feet are attached eccentrically to the shaft and are suspended in the air, and they revolve with the machine while digging. When it is desired to move the dragline the boom is swung in the opposite direction and the large central shaft is revolved. This brings the feet in contact with the ground, and with them as a fulcrum the machine literally picks itself up and moves backward as the shaft revolves.

Whatever the mounting, draglines are so constructed that they can revolve through a full 360° and dig from any angle.

Although a few draglines are powered by steam, the great majority use gasoline or oil as fuel or are fitted with electric motors. Both semi-Diesel and full Diesel engines are employed.

Except in extremely large units, only two men are required to operate a dragline, and ordinarily only one is necessary.

Structural limitations.--The dragline is so constructed that it operates from the surface of the ground in most cases. The only part of the machine which actually enters the excavation area is the digging bucket and its control cables. As a result, it can be used with equal facility in digging from a dry pit or from below the surface of ground water in a wet pit.

Although the design of the dragline facilitates its operation in excavating from below the level on which the machine rests, it can dig material above this level. Excavation from a higher level is limited to a height equal to the bucket clearance when swung from the end of the boom. However, the dragline would be out of the question for continuous operation above the level on which the machine rests as, due to the nature of excavation, dirt is pushed ahead of the bucket and piled up around the machine, and if it attempted to dig at a level above that on which it sits the machine would soon be buried by material pulled in ahead of the bucket. Draglines are not used to excavate banks higher than the vertical reach of the machine.

The lateral or horizontal reach of the dragline is governed by the length and angle of the boom. As the angle of the boom is lowered the horizontal distance the bucket can be swung increases, and vice versa. Dragline buckets are hung from the boom by steel cables, and such connection permits a skilful operator to use the centrifugal force obtained in swinging to cast the bucket beyond the end of the boom. This excess reach varies considerably with the height of the boom point and consequent length of cable, the speed of rotation, the weight of the bucket, and the skill of the operator. Manufacturers usually estimate it at one third to one half the dumping height. The ability to cast the bucket is used to dig beyond the end of the boom and to cast the bucket's contents at a greater distance when dumping on waste or stock piles. Obviously, it cannot be used when loading haulage equipment. It may be well to point out here that when the boom is raised to a high pitch angle the bucket can be cast farther beyond the point of the boom due to the longer length of the hoist cable and pendulum action at the greater pitch angle. But as the boom is peaked up the radius of the boom point decreases, and the aggregate of radius plus distance to which the bucket can be cast decreases as the pitch angle of the boom is increased, so that nothing is gained by peaking the boom. For ordinary operation the best pitch angle will range from 30° to 37°.

The vertical depth to which a dragline can dig is limited by the length of the boom, the angle of repose of the material dug, and the length of the hoist cable. As ordinarily furnished, the cable length will permit a single wrapping on the hoist drum. Where excavation is required at excessive depths longer cables are furnished, and either longer drums are provided or the cable is permitted to wind in two layers. The depth of cut is also governed by the proximity of the machine to the edge of the cut. Deeper cuts can be made in easily dug material than in sticky clay, for instance. Moreover, cuts made from the side are usually shallower than those made from the end.

The height at which the dragline can dump material is governed by the length and angle of the boom.

The dragline boom is longer than that on a power shovel of similar characteristics. This extended boom presents problems in stability which are at times more serious than those with power shovels. The dragline boom angle can be varied at the will of the operator. Also the same dragline may be fitted with different lengths of boom. As the boom is lengthened or the angle decreased, the center of weight of the bucket is extended, hence the force tending to overturn the dragline is increased. Therefore flatter angles or longer booms require lighter buckets and loads. In the past this tendency go overturn has been counteracted by placing heavy weights on the opposite end of the dragline. Such extra weight for counterbalancing may take care of the overturning of a load, but it does not relieve the additional stresses imposed in all members due to overload. Modern machines are designed for the best combination of bucket and load, boom and length, and range of boom angles for the specific unit. The combined effect of any changes in these limits should be studied carefully before being made.

A lengthened boom or flattened boom angle with its attendant increased distance of the center of weight of the bucket from the center of rotation also retards the accelerating and decelerating ability of the machine. Therefore, the advantage gained by a lengthened operating reach is at the expense of stability and rotating speed, unless a smaller bucket is used. In any case, extension of reach on a specific machine results in reduced operating capacity.

Draglines ordinarily are mounted on caterpillar trucks, although the skid and roller type as well as the walking draglines are also a vailable.

The skid and roller mounting requires a pit crew in addition to the operator whenever the machine must be moved. The caterpillar mounting provides for turning at varying radii lengths depending upon the method of drive installed by the manufacturer.

The walking type is so constructed that it can make an immediate change in direction at any angle without recourse to a curved path.

Either type of mounting as ordinarily furnished has ample bearing surface per unit of weight to permit its movement and operation over ordinary surface soil. For exceptionally soft ground extra wide treads are available for side digging and extra long treads for end digging.

Primary power for draglines may be electricity, gasoline, oil, or steam, although the use of steam power is being superseded by one of the other types. Draglines using electricity as primary motive power can operate only when within reach of power cables. Those in which the primary power is steam, gasoline, or oil, on the other hand, can operate independently under their own power. Draglines excavating sand and gravel usually have little need for movement over long distances, hence travel speed becomes of minor importance.

In the preceding paragraph reference was made to primary power. Some installations provide a combination of power in which the primary unit is driven by alternating current and which in turn drives a direct current generator furnishing current for the operating motors. In others the primary power is a semi-Diesel or full Diesel engine driving an electric generator to furnish current for the motors. Another combination is a Diesel engine for the primary power unit which drives an air compressor, which in turn supplies compressed air to the operating engines. Each type of primary power or power combination has its supporters, but the advantages or disadvantages of either are not within the scope of this paper.

The dragline operates from the surface of the ground. Therefore, where the surface is rough or hilly, it must be able to rotate the superstructure 180° or more to prepare a pathway where necessary. Draglines can negotiate grades up to 30 percent where the condition of the ground surface is such that the available tractive force may be applied, but during excavation they operate from a level base. Designed to remove material from below its floor level, the dragline advances as excavation proceeds from the side or retreats as excavation advances from the end. By passing over barren patches and leaving them in place, it can exercise considerable selectivity in mining.

Service equipment required.--The dragline is not in itself a transportation unit, although in certain excavation jobs one dragline may dig and a second transfer the dug material from the first unit to the dump. This is not the practice in sand and gravel operation, however. In such excavation, its range of transportation is limited by the length of its boom. However, where the dragline is used to strip overburden and cast it to the excavated pit, it then becomes a transportation as well as an excavation unit. Because of its longer reach it is more frequently used for this purpose than tthe power shovel. In fact, in stripping a dragline has frequently replaced a power shovel and its complement of locomotive and cars.

In gravel excavation, however, the dragline must depend upon some other unit for haulage service. Because of the uneven surface, conveyor belts are seldom used to serve draglines. Autotrucks and locomotives and cars are the types used most frequently. Like power shovels, draglines provide a continuous service, and to work at greatest efficiency they should be served by transportation equipment affording a like service. However, where a dragline is engaged in removing the overburden and underlying gravel in a single cut simultaneously, it may take advantage of delays due to haulage equipment and strip overburden during the absence of cars or trucks. Of course, the productive capacity of the dragline is reduced by the time required to strip.

Draglines with primary electric power are served through flexible armored cables, the slack of which is allowed to drag over the ground or is coiled on reels. While each advance of the dragline requires an adjustment of cable length, ordinarily this does not require an appreciable loss of time when properly supervised.

Steam-, gas-, or oil-powered draglines require attendant vehicles to supply fuel and water. Coal, oil, or gasoline usually are supplied by the haulage unit. Portable pipe lines are sometimes laid to supply water or liquid fuel.

The information shown in tables 10 and 11 has been taken from catalogs of various dragline manufacturers to present in condensed form the different sizes of draglines available, their capacities (as copied from table 13), and their minima and maxima limits of operating range, weights, and power plants.

Figure 2 illustrates the dragline working ranges referred to in table 10.

In condensed tables such as these, some confusion may arise owing to the fact that a dragline designed to operate one size of bucket with a corresponding boom length may also use a smaller or larger bucket with equivalent long or shorter booms. The tables are not presented to show recommended sizes for sand and gravel excavation. Their function is to show the reader the sizes, operating ranges, weights, and power plants which are available in the market. Detailed selection of size and range must be left to fit local conditions and the mechanical details of the particular machine involved.

TABLE 10.--Dragline working ranges

Bucket capacity, cubic yards	Working capacity, tons per hour		Boom angle, degrees		Boom length, feet		Maximum dumping height, feet		Maximum dumping radius, feet		Maximum digging radius, feet		Maximum depth below grade, feet	
	Minimum	Maximum	From	To	From	To	From	To	From	To	From	To	From	To
3/8	30	63	25	45	24	40	6.5	32.2	10.0	34.0	16.0	46.0	6.3	17.0
1/2	35	90	22	45	25	65	7.7	35.25	18.0	67.0	26.0	82.0	8.0	33.0
3/4	52	127	20	46	30	80	7.25	43.4	25.0	80.0	35.0	85.0	.0	31.0
1	56	145	25	45	30	75	8.25	47.0	30.0	72.5	39.5	81.5	4.7	35.0
1 1/4	69	163	22	45	35	75	9.9	40.5	31.5	74.5	42.0	94.5	9.6	43.0
1 1/2	83	197	22	45	40	80	11.3	43.5	33.5	80.5	43.1	93.0	10.5	36.0
1 3/4	102	230	22	45	45	70	14.5	34.0	30.0	62.0	54.0	77.0	20.0	31.0
2	116	263	20	50	40	90	9.0	56.0	35.0	89.0	57.25	107.0	14.0	40.0
2 1/2	126	260	20	50	50	110	11.5	70.0	44.8	98.6	54.8	120.0	10.0	50.0
3	151	315	20	45	60	137	11.4	70.0	50.25	142.0	57.0	160.0	8.0	61.0
3 1/2	158	300	20	50	60	90	10.0	56.5	44.0	82.0	54.0	102.0	40.0	48.0
4	178	300	18	45	80	137	31.0	67.3	65.25	146.5	83.0	180.0	30.0	82.0
5	145	326	18	45	80	175	20.0	79.3	65.25	184.0	83.0	214.0	29.0	92.0
6	180	392	18	30	100	200	16.0	93.0	100.0	210.0	115.0	244.0	25.5	96.0
8	240	522	18	30	125	185	28.8	85.0	126.0	196.0	147.8	227.0	22.0	102.0
10	300	660	18	30	160	170	29.0	76.0	158.0	183.0	169.0	210.0	72.25	107.0

TABLE 11.--Dragline weights and power plants

Dipper capacity, cubic yards	Dragline weight, pounds		Gasoline							
			Minimum				Maximum			
	From	To	Horse-power	Cylin-ders	Stroke and bore	R.p.m.	Horse-power	Cylin-ders	Stroke and bore	R.p.m.
3/8	14,000	25,000	37	4	4 by 5	1,200	43	6	3 3/8 by 4 3/4	1,200
1/2	21,800	80,000	43	6	3 3/8 by 4 3/4	1,000	110	4	6 3/4 by 8	800
3/4	28,000	117,400	52	6	4 by 4 3/4	1,000	153	6	6 1/2 by 7	1,000
1	49,000	120,000	75	4	5 1/4 by 6 1/2	1,060	160	6	6 by 7 1/4	1,100
1 1/4	65,000	155,000	82	4	6 by 7	900	153	6	6 1/2 by 7	1,000
1 1/2	68,000	188,000	92	4	6 1/2 by 7	865	160	6	6 by 7 1/4	1,100
1 3/4	82,000	128,000	92	4	6 1/4 by 7	865	160	6	6 by 7 1/4	1,100
2	110,700	295,000	150	6	6 by 7 1/4	1,000	160	6	6 by 7 1/4	1,100
2 1/2	154,800	295,000								
3	220,000	465,000								
3 1/2	295,000	465,000								
4	295,000	465,000								
5	465,000	1,450,000								
6	581,000	1,950,000								
8	1,350,000	1,950,000								
10	1,350,000	1,950,000								

TABLE 11.--Dragline weights and power plants--Continued

Dipper capacity, cubic yards	Diesel								Electric	
	Minimum				Maximum					
	Horse-power	Cylin-ders	Stroke and bore	R.p.m.	Horse-power	Cylin-ders	Stroke and bore	R.p.m.	Minimum horse-power	Maximum horse-power
3/8										
1/2	50	3	6 by 8	650	97	4	7 1/2 by 10 1/2	475	25	75
3/4	80	4	6 by 8	900	153	6	6 1/4 by 8 3/4	1,000	30	100
1	70	4	6 1/2 by 8 1/2	500	153	6	6 1/4 by 8 3/4	1,000	40	160
1 1/4	50	4	6 by 7	865	153	6	6 1/4 by 8 3/4	900	50	125
1 1/2	85	4	7 by 8 1/2		153	6	6 1/4 by 8 3/4	1,000	60	200
1 3/4	120	4	9 by 12	375	153	6	6 1/4 by 8 3/4	1,000	60	75
2	148	6	6 1/4 by 8 3/4	900	210	6	9 by 10 1/2	500	60	200
2 1/2	120				270	5	10 by 12 1/2		125	200
3	120				270	5	10 by 12 1/2		100	450
3 1/4					270	5	10 by 12 1/2		150	
4	210	3	14 by 17	300	270	5	10 by 12 1/2		100	350
5	210	3	14 by 17	300	350	5	14 by 17	300	100	800
6	280	4	14 by 17	300	350	5	14 by 17	300	160	850
8					450	5	14 by 17	360	500	850
10					450	5	14 by 17	360	500	850

Capacity.--The rated or theoretical capacity of a dragline excavator depends upon the weight, design, and size of the bucket, the type and application of the source of power, the hoist, swing and drag speeds, the accelerating and decelerating ability, the type of mounting, and the ease of operation.

The actual or working capacity is affected by all of these elements as well as others, such as the condition of the ground surface, wet or dry digging, whether the machine must strip as well as dig gravel, the character of the material to be dug, the relation of bucket size and weight to boom length, the service rendered by the haulage unit, and the efficiency of the operator.

The variation in the working capacity of a single dragline operating under different conditions and personnel is probably as great as that with the power shovel.

The working capacity of a dragline is measured by the quantity of material it can dig and load in a given time. Other things being equal, its theoretical capacity for a few minutes of operation would be the same as its working capacity, but as in the case of the power shovel the other factors are never equal, and the calculation or estimation of working capacities must take into account the influence of those factors. The estimate of capacity in which the gravel operator is interested is that which is computed with due consideration to all possible delays. To make such a calculation it is necessary to evaluate such delays. In the author's opinion, it is impossible to reduce such evaluations to mathematical precision with respect to dragline operation.

Seasonal and local weather conditions will curtail annual capacity. The depth of the bank will affect capacity. A thick bank will permit more time for excavation with less time lost in moving the dragline. Where the dragline removes overburden as well as digs gravel, the amount of character of the overburden, as well as the method of disposal, will affect the digging time of the machine. Draglines are powerful machines and can themselves remove vegetation from the surface if it is not too large. Where large trees or stumps are encountered, the dragline can be used to pull them, but it is usually cheaper to remove them by other means. A stiff clay overburden will require more of the dragline's time in stripping than a light loam of the same thickness. Likewise, a boulder-strewn surface will take more time. When such conditions become excessive it is more economical to use separate machines for stripping and digging gravel.

The depth below the machine's working level from which gravel is recovered will affect the working capacity somewhat, since the greater the depth the more time is required to lower and hoist the bucket.

Since the bucket may be lowered and hoisted while swinging, this delay may be of minor or negligible importance. However, when the dragline is digging from excessive depths in wet pits, the delay becomes important.

A bank of cemented gravel or one containing boulders embedded in fine sand or gravel will require more digging time and hence reduce capacity. This

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condition often becomes serious when the material lies below water level. In wet excavation, constant agitation by the digging bucket roils the water, and the operator cannot see the bucket while digging. Thus, from one cause or another, the bucket may travel repeatedly over the same track. This results in an irregular pit bottom of alternate ditches and ridges. If there is an excess of boulders present they will collect in these ditches. Under such conditions the bucket often slides over the rolling boulders for some distance before finding an opportunity to dig, the loading time is extended, and capacity is reduced.

In dry excavation the gravel deposit may contain lenses of damp, sticky clay. As the bucket is drawn through them considerable resistance is encountered by increased side and bottom friction. This slows up the digging cycle or increases the power requirements. Such conditions, when encountered in wet pits, may greatly increase this difficulty by increasing the suction which resists the lifting of the bucket.

The ability of the dragline to penetrate and dig gravel depends upon the design and weight of the bucket and the power behind the drag cable. Unlike the shovel, the dragline has no means of forcing the bucket into the bank. Thus a heavily cemented gravel will require a heavier bucket of radically different design than is required for a loose sand deposit. Therefore, unless the bucket is properly designed for the local conditions, either capacity will be reduced or a needless expenditure of power will result. In any case, cemented material will require more time and reduce the dragline capacity.

The type of haulage equipment servicing the dragline, as well as the power shovel, has an important bearing upon its capacity. Where the dragline performs the double duty of stripping and digging gravel, delays of transportation equipment are not so serious, since the dragline can strip during the absence of haulage equipment. This, of course, applies only where the overburden can be cast to waste and does not have to be loaded into haulage equipment like the gravel. Where the dragline is engaged in digging only it depends entirely upon the haulage equipment for continuous operation. If the haulage unit is a locomotive and cars, the larger the cars the greater will be the capacity of the dragline, as the bucket need not be so accurately spotted for dumping with a larger car and the dragline time cycle is thus reduced. The field belt conveyor is seldom used to serve draglines because it would be necessary to operate it over the natural surface of the ground. This is seldom as level as the working level left behind the power shovel.

In some excavation work the transporting unit for the digging dragline is a second dragline, but this condition seldom is feasible in gravel excavation.

The lay-out of the excavation plan will also affect the capacity of the dragline. The effect, however, differs from that on the power shovel. For instance, the dragline can excavate a thoroughcut with as much facility as a bench cut. Since the transportation unit is always on the surface it is unnecessary to increase the dragline swing circle to more than a 90° average as would be necessary with a power shovel. The relative elevation of dragline and haulage equipment remains constant; hence the operator can adjust swing and hoist operations to a minimum cycle.

The efficiency of the dragline operator has a decided affect on the capacity of the machine. The long boom of the dragline, combined with the pendular swing of the loaded bucket, requires time to spot it accurately for dumping. Likewise, the same elements require time to spot the bucket at the required point for digging. A skillful operator will take advantage of the swing of the bucket and time the dump to coordinate with it, while a less skillful man will have trouble. An experienced operator usually can distinguish by the pull of the drag cable when his bucket is full and thus start hoisting without unnecessary loss of time in dragging a full bucket. Neither does he lose time in hoisting the bucket higher than is necessary to clear the haulage equipment. Every action of the dragline is started and controlled by the operator. Therefore its performance must reflect the ability of the operator. However, mechanical construction and power application differ for different makes of machines. These may fit one machine better for certain local conditions than another, or the personal preference of the operator due to his past experience may make him more expert in handling one type than another. Thus, capacity rate may differ greatly on the same dragline when operated by different individuals.

From a review of the elements that affect working capacity it is readily seen that most of them are of an intangible nature incapable of accurate valuation. The author feels therefore that exact mathematical calculations cannot be applied to dragline working capacities. However, approximate calculations of theoretical capacity are in order. The delay factors affecting divergence between theoretical and working capacity can then be lumped together and their combined effect discounted by establishing a constant in the form of an arbitrary ratio between calculated theoretical capacity and actual working capacity. The result admittedly does not apply to specified conditions. To obviate this difficulty, the theoretical capacity should be calculated to show the range between difficult and easy digging. The working capacity will then show a similar range for minimum and maximum performance within which the operator can evaluate the effect of his local conditions.

Various authors have calculated dragline capacities in various ways. The author has found the following method simple, easy to apply, and sufficiently accurate for general application.

Theoretical capacity is a function of the size of the bucket and the time required for a complete dragline cycle through loading, swinging, dumping, and returning to the digging position. The bucket capacity is fixed by size. The loading time is calculated by the speed of the drag cable using minimum and maximum distances through which the bucket must be dragged to fill. The swing and return time is calculated from the rotating speed of the dragline with due consideration to accelerating and decelerating ability and average angle of swing.

Dragline operations consist of four motions; digging, hoisting, lowering the bucket, and swinging the boom. The bucket can either be hoisted or lowered while the boom is swinging, but while the bucket is being loaded the boom must be stationary. Ordinarily enough time is required in swinging the boom from pit to car or from car to pit to allow the bucket to be hoisted or lowered in the same interval. Therefore hoisting speed is not considered in calculating the cycle time. For exceptional conditions such as digging from excessive depths, however, hoisting speed must be considered. Standard design is such that for ordinary operation the swing time will balance hoisting time, but for deep excavation the two speeds become unbalanced and the hoisting speed must be taken into consideration.

Swinging time is calculated from the rotating speed of the machine. Acceleration and deceleration ability necessarily affect the swinging time, and because of the longer boom they hage a greater effect on the dragline than on the power shovel. However, to evaluate accurately the effect of these two elements would require a study of the mechanical forces involved and their application in different makes of machines. Such a discussion is not within the scope of this paper and should be left to the manufacturing engineer for calculation. To obviate the effect of these elements, the writer prefers to combine them with the other intangible delay elements in the ratio between theoretical and working capacity.

The loading time is calculated from the speed of the drag cable and the distance necessary to fill the bucket. Ordinarily a dragline bucket can be depended upon to fill in three to six times its own length. In loose sand a heavy bucket probably will fill in its own length. In cemented gravel or boulders it may require more than six times its length to fill. Calculation of loading time based on exact bucket length for each size would involve too large a table for easy use. Moreover, accuracy would not be gained by such an assumption because the design of the bucket influences its digging ability. For example, a wide, short bucket would fill in a shorter dragging distance than a narrow, long bucket. On the other hand, the wider the bucket the more power is required to load it. A light bucket will exert less pressure and therefore have less penetrating power to carry its cutting edge below the surface. The angle of the cutting edge or teeth, as well as the point at which the drag bridle is attached, also affects the penetrating power of the bucket. An analysis of the dimensions of buckets built by one manufacturer shows that for each cubic foot of measured capacity the 1/2-cubic-yard bucket has 2.12 inches of width while the 8-cubic-yard bucket has only 0.34 inch of width. The same analysis shows the smaller bucket to weigh 105 pounds per cubic foot of capacity as against 85 pounds for the large size. Thus while the ratio of weight to bucket size is fairly constant, the width ratio varies considerably. Thereofre, the length of drag sufficient to fill a small bucket should be less with its greater width-to-capacity ratio.

For this analysis dragline buckets are divided into three groups; small intermediate, and large. For each group the average bucket length has been obtained, and the average minimum and maximum drag distances have been calculated as follows:

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Minimum and maximum drag distances, feet

Bucket size, cubic yards:	Minimum (3 times average bucket length)	Maximum (6 times average bucket length)
3/8, 1/2, 3/4	10	20
1, 1 1/4. 1 1/2. 1 3/4, 2, 2 1/2, 3	15	30
3 1/2, 4, 5, 6, 7, 8	20	40

Dumping time is assumed at an average minimum of 2.1 seconds and an average maximum of 4.4 seconds. These are taken arbitrarily and correspond to the average dumping time tabulated for power-shovel dippers. Dumping time enters the dragline time cycle only when the dragline is loading some form of transportation equipment. When the dragline is engaged in casting overburden to waste piles there is no dumping time as such. The bucket is cast while the machine changes its direction of swing.

The average swing of a dragline may be taken as 90°, and this will cover all but a few unusual conditions. Therefore the average swing and return angle is 180°.

Swing and return time may then be calculated in seconds as was done for power shovels.

$$\frac{60 \text{ seconds times } 180^\circ}{360^\circ \text{ times r.p.m.}}.$$

Loading time in seconds is calculated as follows:

$$\frac{60 \text{ seconds times drag distance}}{\text{Speed of drag cable in feet per minute}}.$$

Table 12 has been compiled to give the swing and return time for draglines with various rotating speeds. The loading time for different lengths of drag and drag-cable speeds is also given.

By adding the theoretical swing and return time, the appropriate loading time (both given in table 12), and the assumed dumping time, the minimum and maximum theoretical cycle time for a given dragline may be obtained.

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TABLE 12.--Data required for calculation of dragline time cycle for an average swing of 90°

Speed of rotation, r.p.m.	Swing and return time, seconds	Dragline speed, f.p.m.	Loading time in seconds for different lengths of drag in feet, 1/				
			10	15	20	30	40
0.5	60.0	100	6.0	9.0	12.0	18.0	24.0
.8	37.5	105	5.7	8.5	11.4	17.1	22.8
.9	33.3	108	5.5	8.3	11.1	16.6	22.2
1.0	30.0	110	5.4	8.2	10.9	16.3	21.8
1.1	27.3	112	5.3	8.0	10.7	16.0	21.4
1.5	20.0	114	5.2	7.9	10.5	15.8	21.0
1.8	16.7	117	5.1	7.7	10.2	15.4	20.5
		119	5.0	7.6	10.1	15.1	20.2
2.0	15.0						
2.5	12.0	120	5.0	7.5	10.0	15.0	20.0
2.75	10.9	123	4.8	7.3	9.8	14.6	19.5
		125	4.8	7.2	9.6	14.4	19.2
3.0	10.0	127	4.7	7.1	9.5	14.2	18.9
3.1	9.7	128	4.6	7.0	9.4	14.1	18.8
3.2	9.4	129	4.6	7.0	9.3	13.9	18.6
3.25	9.2						
3.5	8.6	130	4.6	6.9	9.2	13.8	18.4
3.6	8.3	132	4.5	6.8	9.1	13.6	18.2
3.75	8.0	134	4.4	6.7	9.0	13.4	17.9
		135	4.4	6.7	8.9	13.3	17.8
4.0	7.5	137	4.3	6.6	8.8	13.1	17.5
4.1	7.3						
4.25	7.1	140	4.2	6.4	8.6	12.9	17.2
4.3	7.0	145	4.1	6.2	8.3	12.4	16.6
4.5	6.7	148	4.0	6.1	8.1	12.1	16.2
4.75	6.3						
		150	4.0	6.0	8.0	12.0	16.0
5.0	6.0	155	3.8	5.8	7.7	11.6	15.5
5.25	5.7						
5.5	5.5	160	3.7	5.6	7.5	11.2	15.0
		162	3.7	5.5	7.4	11.1	14.8
6.0	5.0						

1/ Dumping time is assumed to range from an average minimum of 2.1 seconds to an average maximum of 4.4 seconds.

Thus a 3/4-cubic-yard dragline having a rotating speed of 4 r.p.m. and a drag-cable speed of 150 feet per minute would have a theoretical cycle time ranging from 13.6 to 19.9 seconds, calculated as follows:

Swing and return time for a rotating speed of 4 r.p.m. from table 12 in seconds	7.5	7.5
Loading time for a cable speed of 150 feet per minute and 10-foot drag	4.0	
Loading time for 20-foot drag		8.0
Minimum and maximum dumping time assumed at	2.1	4.4
Minimum and maximum cycles	13.6	19.9

The theoretical capacity of the machine in cubic yards per hour may then be calculated as follows:

$$\frac{\text{3,600 seconds times bucket capacity in cubic yards.}}{\text{Cycle time in seconds}}$$

For example, the dragline used in the previous example, having a cycle range of 13.6 to 19.9 seconds, would have a theoretical capacity-range of 136 to 200 cubic yards per hour.

Calculated in this manner, the author has found the ratio of working capacity to theoretical capacity is about 1 to 3; thus the working capacity of the dragline in the preceding example is estimated to range from 45 to 67 cubic yards per hour.

Draglines made by different manufacturers as shown by their catalogs have different rotating and drag-cable speeds. Table 13 is compiled from the information given in manufacturers' catalogs, and capacities are computed after the author's method.

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TABLE 13.—Estimated range of dragline capacities

Bucket size, cubic yards	Rotating speed, r.p.m.		Dragline speed, r.p.m.		Time[1/] cycle, seconds		Theoretical capacity, cubic yards per hour		Capacity, tons per hour			
									Theoretical[2/]		Working[3/]	
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
					10 to 20 feet of drag							
3/8	4.0	5.5	135	150	11.6	21.5	63	116	91	188	30	63
1/2	3.1	6.0	110	162	10.8	25.0	72	167	104	270	35	90
3/4	3.0	5.25	110	162	11.5	25.3	107	235	155	380	52	127
					15 to 30 feet of drag							
1	3.0	5.5	108	155	13.4	31.0	116	269	168	436	56	145
1 1/4	2.7	4.5	110	143	14.9	31.6	142	302	206	490	69	163
1 1/2	2.7	4.5	110	150	14.8	31.6	171	365	248	592	83	197
1 3/4	2.7	4.5	123	150	14.8	29.9	211	426	306	690	102	230
2	2.5	4.5	132	150	14.8	30.0	240	486	348	788	116	263
2 1/2	1.8	3.0	134	137	18.7	34.5	261	481	378	780	126	260
3	1.8	3.0	134	140	18.5	34.5	313	584	454	946	151	315
					20 to 40 feet of drag							
3 1/2	1.8	2.5	137	140	22.7	38.6	327	555	474	900	153	300
4	1.8	2.0	134	137	25.9	39.0	369	556	535	900	178	300
5	.8	1.5	134	155	29.8	59.8	301	604	436	978	145	326
6	.8	1.5	150	155	29.8	57.9	373	725	541	1175	180	392
8	.8	1.5	150	155	29.8	57.9	497	967	720	1565	240	522
10	.8	1.5	150	155	29.8	57.9	622	1221	902	1980	301	660

[1/] The time cycle is the sum of the time required to swing and return, load, and dump. Dumping time is assumed as ranging from 2.1 to 4.4 seconds.

[2/] Sand and gravel estimated to range from 2,900 to 3,240 pounds per cubic yard.

[3/] Assumed as one third theoretical capacity. This drastic reduction from the theoretical capacity is designed to account for delays of any nature and at the same time avoid detailed and exact calculations involving the relation of acceleration and deceleration ability, in machines of different size, upon the time of the dragline cycle. Thus reasonable accuracy is obtained by simple calculation without involving explanation of the effect of different mechanical details.

THE CRANE

The traveling crane is one of the most useful tools to be found around an industrial plant. Essentially it consists of a self-propelled chassis on which is mounted a structural steel boom which may carry either a clamshell, orange-peel, or other type of bucket. Traveling cranes are built of many types for various uses. Wrecking cranes are mounted on heavy standard-gage railway cars. They are self-propelled and swing a short, heavy boom. Their principal use is to replace derailed locomotives and cars, and as such they do not wield an excavating bucket. Locomotive cranes are commonly found around industrial plants of many types. They may be mounted on self-propelled, standard-gage, flat cars or short-coupled railway trucks. The boom is longer and of lighter structural-steel construction than the wrecking or excavating crane. They wield light weight clamshell, orange-peel, or other types of buckets and are used principally for loading or unloading freight cars from or to stock piles, transferring stock from one bin or pile to another, and moving heavy machinery. Being self-propelled, they are frequently used to spot railway cars in the absence of the switching locomotive. Mounted on caterpillar traction, this type of crane has the same uses as one on railway trucks but has the advantage of greater mobility. None of these cranes, as ordinarily equipped for use around an industrial plant, is, strictly speaking, an excavator crane, although any of them may be used for that purpose.

The crane as used for excavating purpose is essentially the same as the locomotive crane, used as a transfer unit, but it is usually fitted with a shorter boom mounted on a chassis similar to that of the power shovel or dragline. In fact, the dragline boom and chassis may be used as an excavating crane. The bucket swung by the excavator crane is either a clamshell or orange-peel type, but it is of heavier construction than those used for transferring material around industrial plants.

The crane excavator may be mounted on railway trucks, but this type of mounting is uncommon.

Excavator cranes are sometimes, but not often, used for digging gravel. As such, they must depend upon the weight of the bucket to penetrate and dig the gravel. They have no means of forcing the bucket into the bed of gravel as the shovel has with its dipper stick and the dragline has with its drag cable. In operation, the crane lifts its bucket and swings it over the point at which it is desired to dig. The bucket is opened and dropped, striking the deposit with considerable impact. The bucket is then closed by appropriate mechanism without being lifted. The two or more jaws of the bucket, pressed into the ground by the impact and held by the bucket weight, gather the material within their reach as they are closed.

The cycle of operations is similar to that of the dragline, that is, swinging and dropping the bucket to the loading position, closing the bucket (corresponding to the dragging time of the dragline), hoisting and swinging the bucket to the dumping position, and opening the bucket for dumping. Hoisting and swinging may be simultaneous actions. Dumping and loading are separate, and each requires time.

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The clamshell bucket is not satisfactory in hard digging such as cemented gravel, since it must depend upon its weight and impact to penetrate the bed. The orange-peel bucket, because of its pointed cutting edges, penetrates tough ground easier but is also easier to get out of order from rough usage.

Either bucket may be used on the crane for dry or wet excavation, and under certain conditions the orange-peel bucket has been used very successfully to remove large boulders from beds lying under water.

When used for wet pit or marine excavation, the crane is commonly mounted on a floating scow and as such will be discussed under dredges.

Like the dragline, the crawler crane usually moves over the surface of the ground and excavates material from below that level. It removes a horizontal slice by individual bucket loads. Because of its operating position and the method of digging, it is capable of greater selectivity in mining than either the shovel or dragline. It may also be used to strip overburden as well as to excavate gravel from the same position.

Capacity.--The rated or theoretical capacity of a crane depends upon the weight, design, and size of the bucket; the type and application of the source of power; the speed of the hoist line, boom rotation, and bucket closing line; the accelerating and decelerating ability; the type of mounting; and the ease of operation.

The actual or working capacity is affected by all of these elements as well as by others such as the condition of the ground surface with regard to mobility, wet or dry digging, whether the machine must strip as well as dig gravel, the character of the material to be dug, the position of the gravel with relation to the crane's operating level, the height of bank or depth of cut, the relation of bucket size and weight to boom length and pitch angle, the service rendered by the haulage unit, and the efficiency of the operator.

There may be as much variation in the working capacity of a single crane operating under different conditions and personnel as with the power shovel or dragline.

The working capacity of a crane, like that of the shovel and dragline, is measured by the amount of material it can dig and load in a given time. Other things being equal, its theoretical capacity for a few minutes of operation would be the same as its working capacity, but the other factors are never equal, and the estimation of working capacities must take into account the influence of those factors. The capacity estimate in which the gravel operator is interested is that which is computed with due consideration for all possible delays. To make such a calculation it is necessary to evaluate such delays. The author believes that it is impossible to reduce such evaluations to mathematical precision with respect to crane excavation.

The capacity of a crane excavator will be affected by seasonal and weather conditions. Thick gravel beds afford greater and more regular capacity by decreasing the time lost in moving. However, digging from excessive depths reduces capacity by requiring more hoisting time. A bank of cemented gravel offers more resistance to the crane bucket than to a dragline or shovel. Likewise, imbedded boulders retard the digging rate and hence reduce capacity. As with the dragline, a rough surface retards the mobility of the crane, but it can prepare a path for itself in the same manner, although the path may not be as smooth.

In wet pits muddy water prevents the operator from placing the bucket by sight. In deep pits where the gravel lies below a considerable depth of water, more time is required for the bucket to sink to the bottom than if it were dropped through the air in dry excavation. This delay is less apparent in hoisting. However, the retarding effect of suction in disengaging the loaded bucket from the gravel bed may be greater with the crane than the dragline because the crane must exert its lifting power in a direct vertical pull without the help of the side motion afforded by the drag cable. In such cases capacity may be reduced by time lost in starting the loaded bucket.

If the crane bucket is properly designed for a certain boom length or angle and the former is lengthened or lowered, capacity suffers because a smaller bucket must be used with the increased radius, otherwise there will be danger of overturning the machine.

Like that of all other types of excavating equipment, the capacity of the crane depends upon the service rendered by the haulage unit and the skill of the operator.

The lay-out of the excavation plan will have less effect on the crane capacity than with a shovel or dragline. The action of the crane is more individualistic. The shovel or dragline operator attempts to remove a fairly regular cut from the bank by causing each dipper or bucket load to follow that previously removed. The crane operator, however, can drop his bucket and remove a load from any point within the radius of his boom, irrespective of where the previous load was taken. This ability allows considerable selective mining and permits the operator to dig around obstructions such as sunken logs or trees in a river bed. Thus, in some types of difficult digging the crane may be much more efficient than other equipment. On the other hand, the crane is not so well adapted to systematic excation along a regularly laid-out scheme.

The long boom of the crane, combined with the pendular swing of the bucket and the time required to open the bucket for dumping, offers a chance for appreciable variation in capacity due to operating skill. The crane bucket is slower to release and dump than that of the shovel.

When cars are being loaded the boom must be spotted and held stationary while the bucket is dumped. In casting to waste or storage piles this is not necessary. Mechanical equipment and power application differ with the machine, and one machine may fit local conditions better than another, or the operator's past experience may make him more proficient with one than the other. Since every action of the crane must be started and controlled by the operator, the capacity of a given machine depends to a great extent on the skill and ability of the man at the levers.

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Thus it is readily seen that most of the elements affecting crane, as well as shovel and dragline, working capacity are intangible and incapable of accurate valuation. Therefore exact mathematical computations are impossible. The author has found that crane capacities may be computed theoretically, as was done for shovels and draglines, based on rotating speed. The theoretical capacity thus found must be reduced by at least 75 percent to obtain conservative working-capacity figures.

Because cranes are not commonly used for sand and gravel excavation it is not deemed necessary to present capacity tables in this report. However, in passing, it may be pertinent to state that the time required by the average operator to dump either the clamshell or orange-peel bucket will more nearly equal the time required to load it than is the case with the shovel. This accounts for part of the higher ratio used in calculating working capacities from theoretical capacities with cranes.

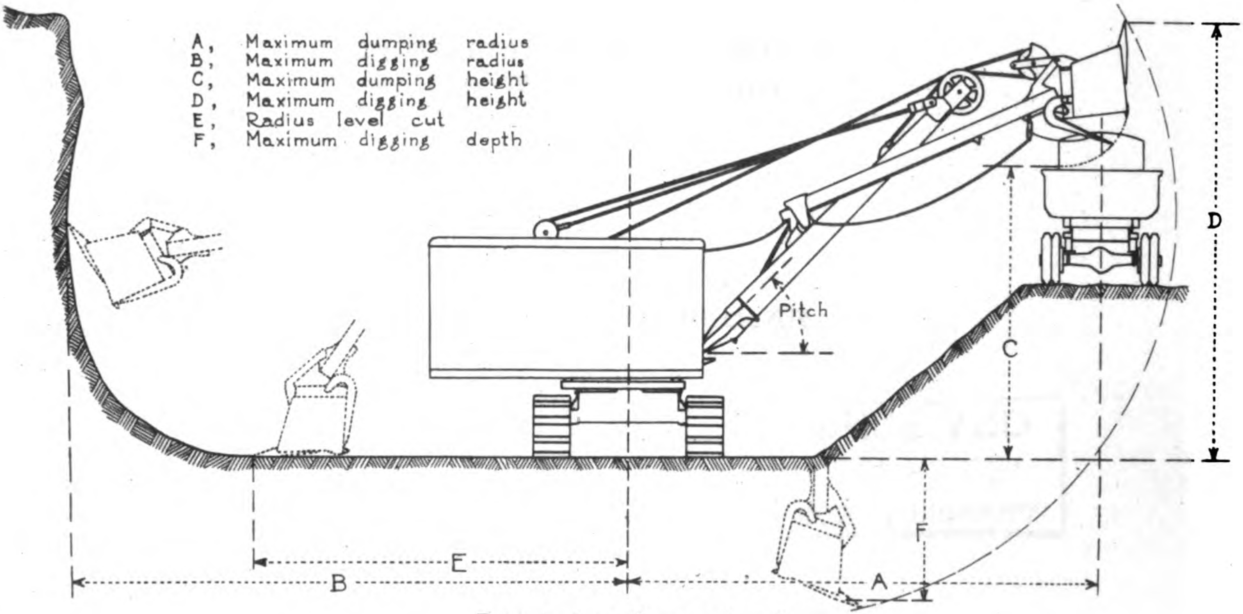
A, Maximum dumping radius
B, Maximum digging radius
C, Maximum dumping height
D, Maximum digging height
E, Radius level cut
F, Maximum digging depth
Pitch
A
B
C
D
E
F

Figure 1.— Power shovel.

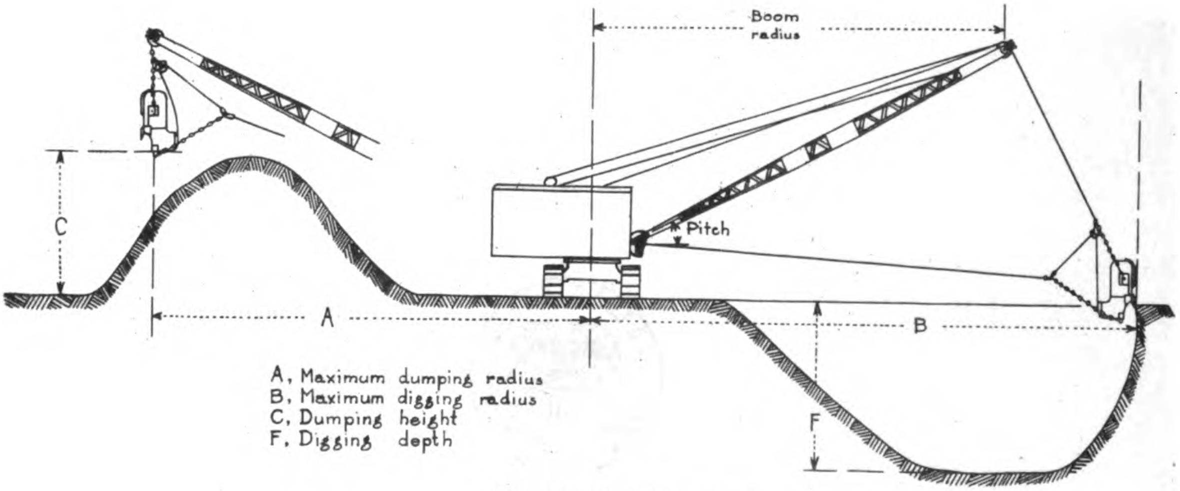

Figure 2.—Dragline.